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Derivation of Motor Vehicle Exhaust Emission Rates. Appendix E to Mobile Source Emission Factors

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Derivation of Motor Vehicle Exhaust Emission Rates

APPENDIX E

to

MOBILE SOURCE EMISSION FACTORS

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This appendix contains information on "Derivation of Motor Vehicles Exhaust Emission Rates." It is one of seven appendices from Mobile Source Emission Factors (EPA-400/9-78-005 and 006), but was not included at time of publication.

17. KEY WORDS AND DOCUMENT ANALYSIS

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APPENDIX E

PART ONE: DERIVATION OF MOTOR VEHICLE EXHAUST EMISSION RATES

(For All Regions Except California and High-altitudes)

I. LIGHT-DUTY VEHICLES (AUTOMOBILES)

Pollutant emission rates for motor vehicles are determined in several ways:

1. Data is obtained from EPA's Emission Factor Program (EFP) which is a continuing effort to characterize the emissions of light-duty vehicles (LDVS) in their in-use condition. EFP data are generated from surveillance testing of in-use vehicles in seven cities: Chicago, Denver, Houston, Los Angeles, Phoenix, St. Louis and Washington, D. C. Exhuast emission tests were performed on each vehicle in accordance with the 1975 Federal Test Procedure (FTP) as outlined in Chapter I of the Mobile Source Emission Factor Document (March 1978) and as described in detail in the Code of Federal Regulations, Title 40--Protection of the Environment, Part 85--Control of Air Pollution from New Motor Vehicles and New Motor Vehicle Engines. The vehicles tested in each city were selected to be a nationally representative (random) sample of cars within a model year, although the number of vehicles for each model year are not representative of the total population of in-use vehicles.

2. Emissions data is available from the testing of prototype vehicles used by motor vehicle manufacturers to obtain EPA certification that the vehicles will be built to meet the applicable emissions standards.

3. Assembly line test data is obtained through EPA's Selective Enforcement Audit (SEA) program.

4. At times technical judgement must be used to estimate emission rates for future model years when a new, untried technology might be utilized to meet legislated emission standards.

In the final Mobile Source Emission Factor Document, different sets of initial emission levels and emission deterioration rates were estimated for each group of model year vehicles which represented a major technological change in emission control systems, generally due to more stringent emission standards as presented in Appendix D. For LDV hydrocarbon (HC) and carbon monoxide (CO) emissions, the first three categories are pre-controlled (pre-1968 model years), pre-catalyst controlled (1968-1974 model years), and 1975-1979 model year catalyst. For HC there is one additional category of post-1979 catalyst vehicles; for CO there are two additional categories: 1980 model year catalyst and post-1980 model year catalyst. NOx emission rates were estimated for the following emission control categories: pre-controlled (pre-1968 model years), pre-catalyst and pre-NOx controlled (1968-1972 model years), pre-catalyst and NOx controlled (1973-1974 model years), 1975-1976 catalyst, 1977-1980 catalyst and post-1980 catalyst. The initial emission rates and deterioration rates are assumed to be equal for all the model years within each of these emission control categories.

The emission rates for each of the vehicle categories of pre-controlled through 1976 model year vehicles have been determined from the linear regressions of mean emissions on mileage from measurements of vehicles in the Fiscal Year 1971 through FY 1975 Emission Factor Programs (EFP). All emission factors are based on the 1975 FTP regardless of the test procedure in existence at the time the vehicles were produced.

Since no vehicles have yet been marketed to meet all future year LDV emission standards, the following "model" was developed to estimate future model year vehicle emission rates.

Analysis of Emission Factors for Future New Cars

This section contains the data, assumptions and analysis behind the emission factor equations derived for future new cars. Those emissions factor equations are:

Pollutant	Standard	Emission Rate 1/
HC	.9 gpm	.29 + .23Y*
HC	.41 gpm	.13 + .23Y
CO	9.0 gpm	3.8 + 2.3 Y
CO	7.0 gpm	3.0 + 2.3 Y
CO	3.4 gpm	1.4 + 2.0 Y
NOx	2.0 gpm	1.5 + .16Y
NOx	1.5 gpm	1.1 + .16Y
NOx	1.0 gpm	.29 + .22Y**
NOx	.4 gpm	.12 + .22**

*Y equals mileage/10,000
**For any standard between 1.0 and .4 gpm, simply interpolate between the intercepts of these linear equations.

Essentially two independent pieces of analysis were employed in deriving the above emission rates. One was the analysis of the emissions data derived from the testing of low mileage 1975 and 1976 California cars in EPA's Fiscal Year 1974 and 1975 Emission Factor Program (EFP). The data from these programs are presented in Tables E-1, E-2, and E-3.

1/ The coefficient of the y variable, describing the increase in the average automobile's emissions rate (in grams/mile) over 10,000 miles of driving, is a linear estimate of the change in emissions rates caused by increases in mileage. This estimate (of what in most cases is a non-linear relationship) is calculated by subtracting the zero mile emissions rate from the 100,000 mile emissions rate and dividing it by 10.

These data were obtained from 1975 and 1976 model year California cars designed to emissions standards of .9/9/2.0 (HC/CO/NOx). These vehicles were submitted to an EPA contractor on a voluntary basis and because of the recent model years involved were generally low mileage vehicles.

Because of the "volunteer" nature of these data, these cars may not adequately represent the proportion of the vehicle population whose emissions control devices have purposely been rendered inoperative by the vehicle owner. Although EPA has not estimated the impact of a "tampering" owner's reluctance to submit his car to a federally sponsored emissions test, the specific inclusion of this segment of the population would raise the intercept or the mileage coefficient of any emissions factor equations based solely on EFP data.

Because of the low mileage of the cars tested, the limited number of cars tested, and the resultant failure of changes in mileage to explain the variations in emissions levels, the reader is also cautioned against using these data exclusively in deriving emissions factor equations. To the extent that these data have been used in deriving emissions factor equations, EPA has used them in determining the low mileage emissions (essentially the intercept of the linear emission rate equations) of new cars and not in determining deterioration factors (the mileage coefficients). To the extent that the low mileage data can be used to estimate deterioration factors EPA believes that a comparison of the means of the FY 1974 and FY 1975 EFP data is the most useful and appropriate statistical analysis that can be performed on this data.

The second analytical tool employed in deriving the emissions factor equations detailed above is an in-use emissions "model" which attempts to project average model year emissions by specifically accounting for emissions level changes associated with levels of maintenance, tampering and key component failures. This "model", described below, has been used by EPA primarily to estimate the deterioration factors (mileage coefficient) in the equations detailed above. However, EPA has compared the deterioration factors derived from the "model" with deterioration factors derived from the low mileage EFP data and has found that except for NOx the independently derived deterioration factors agree quite closely.

Derivation of Emissions Factor Equations by Pollutant

Key Assumptions: As described above the final emission factor equations were derived from an analysis which combined the findings of in-use California data and an in-use emissions projection "model". In deriving the nine emission rate equations listed above the following key assumptions were made which permitted the extrapolation of in-use data for one set of emissions standards (.9/9/2.0) and of "modeled" emissions levels for two sets of emissions standards (.41/3.4/2.0 and .41/3.4/1.0) to the combinations of emissions standards defined by the possible combinations of standards listed for the nine equations above:

(1) Similar technologies are assumed to deteriorate at the same rate (in grams per mile) in the range of the emissions standards discussed here.

(2) Low mileage EFP data are most useful in determining the intercept of the emissions factor equation.

Hydrocarbons

The emission rates derived for HC at the .9 and .41 gpm standards are:

(.9 gpm) .29 + .23Y
(.41 gpm) .13 + .23Y
where Y = mileage/10.000

These rates are based on the results of the in-use "model" and California EFP data. The .23y deterioration factor (DF) was generated by the "model" and is confirmed by the .238 grams per 10,000 mile difference found between the means of the FY 74 and the FY 75 EFP data for 1975 cars meeting the .9 gpm standard. The use of the same DF at .9 and .41 is based to some extent on the assumption stated in the introduction of this paper concerning the deterioration of similar technologies[2/] The intercept for the .9 gpm standard was derived by subtracting the "model" determined DP from the 10,000 mile emissions level projected from EFP data. The intercept at a .41 gpm standard was obtained by equating the ratio of it and .41 to the ratio of the .9 gpm standard intercept and .9.

Comparing the projection of the .9 gpm HC equation to the average 1976 new car fleet emissions (as obtained from FY 74 and FY 75 EFP data for California cars designed to a .9 gpm standard) one finds that at the average EFP mileage (about 8,500 miles) the equation underestimates total emissions by about 30 percent.[3/]

2/In fact because a .41 gpm HC standard will generally be combined with a NOx of 1.0 gpm or lower, there will be a technology shift between .9 and .41, i.e., a move from oxidation catalyst systems at .9 gpm to the 3-way at .41 gpm. The "model" showed a drop in the DF at .41 gpm as a result of this technology shift. However, because of the lack of confirmatory data to support a larger DF at .9 gpm, the lower DF projected for .41 gpm was used at both the .41 gpm and .9 gpm standards.

Footnote 3 on next page...

It is not clear whether this underestimate is due to a low intercept or a low DF. However, it does indicate that the equation may be a conservative estimate of in-use emissions.

Carbon Monoxide

The emissions rates estimated for CO at standards of 9.0, 7.0 and 3.4 gpm are as follows:

(9.0 gpm) 3.8 + 2.3Y
(7.0 gpm) 3.0 + 2.3Y
(3.4 gpm) 1.4 + 2.0Y
where Y = mileage/10,000

Here again the assumption of similar DF's for similar technologies has been applied. In this instance the DF generated by the in-use "model" for the advanced Oxidation Catalyst at a 3.4 gpm standard was used at the 9.0 and 7.0 gpm standard levels (standards at which CO will be controlled with the oxidation catalyst technology). The DF cited for the 3.4 gpm standard level was derived from the in-use "model" estimates for 3-way catalyst systems. The deterioration factor for this technology was estimated to be lower than that for the oxidation catalyst system (2.0 grams/10,000 miles for the 3-way versus 2.3 grams/10,000 miles for the oxidation catalyst systems).

The intercepts for the CO equation were derived in a manner similar to that described for HC. The intercept at a 9.0 gpm standard was calculated by subtracting the "model" generated DF (2.3) from the 10,000

3/The equations for HC, CO, and NOx are based on an in-use "model" and data from 1975 model year California cars. This comparison of the predicted emissions (derived from the equations for HC, CO or NOx) at 8,500 miles with the actual emissions of 1975 model California vehicles was carried out to determine if there is any directional bias to the predictions of the derived equations. For the most part, the equations appear (based on the limited data available) to be underpredicting actual emissions. The percentage figure cited in these comparisons should be viewed as only qualitative and directional.

mile emissions levels estimated for 1975 model year California cars designed to a 9.0 gpm standard. The intercepts for the 7.0 and 3.4 gpm standards were generated by equating the ratios of those intercepts to their appropriate standards with the ratio of the calculated intercept for the 9.0 gpm standard to 9.0 gpm (3.8/9.0).

Comparing the average 8,500 mile emissions of the 1976 California EFP fleet to the 8,500 mile emissions projected by the 9.0 gpm standard equation, one again finds that as with HC the equation underestimates actual CO emissions by about 30 percent.3/

Nitrogen Oxides

The emission rates for 2.0, 1.5, 1.0 and .4 gpm NOx standards are as follows:

(2.0 gpm)	1.5 + .16Y
(1.5 gpm)	1.1 + .16Y
(1.0 gpm)	.29 + .22Y
(.4 gpm)	.12 + .22Y

where Y = mileage/10,000

Unlike the equations estimated for HC and CO, the equations for NOx are derived entirely from the in-use "model". EPA has chosen to reply exclusively on the "model" in this case because of the complete lack of correlation between mileage and emissions levels in the in-use data. EPA believes that the available evidence strongly suggests that tampering and system deterioration will continue to raise Nox emissions with time.

As with HC and CO the equation for a 2.0 gpm NOx standard was compared to the average 8,500 mile emissions estimated from California EFP data for 1976 year cars. The equation was quite accurate in predicting average emissions, overestimating average emissions by only 5 percent.[3/]

Conclusion

The emission rate equations cited above represent an effort by EPA to combine in-use data, theoretical models and major technological assumptions in such a way as to adequately predict the emissions of cars yet to be built. The reader should be advised that these equations may be updated as high mileage in-use data become available.

Table E-1

FY 74 EFP Data for 1975 California Cars

Model Year	Make	Mileage	HC	CO	NOx
75	AMC	9010	0.35	15.09	1.61
"	BUICK	14916	0.89	16.62	5.42
"	"	12626	0.54	5.97	1.88
"	"	5661	0.39	5.07	4.22
"	CADILLAC	21718	0.77	11.70	2.44
"	CHEVROLET	4941	0.30	4.95	4.97
"	"	7683	0.49	2.32	1.58
"	"	5407	0.51	4.29	1.78
"	"	8045	0.86	13.00	1.58
"	"	8459	0.62	4.90	1.77
"	"	1831	0.45	2.49	1.45
"	CHRYSLER	8102	0.44	7.54	3.24
"	DODGE	8999	0.22	1.39	1.79
"	"	3246	0.38	2.37	1.78
"	FORD	6401	0.12	1.36	1.38
"	"	3936	0.78	2.78	2.04
"	"	9743	0.33	1.94	2.77
"	"	5781	0.57	3.25	2.42
"	"	9022	0.64	9.49	1.09
"	MERCURY	9468	0.46	8.09	1.71
"	"	2749	0.38	2.30	3.56
"	OLDSMOBILE	18108	0.74	14.79	0.93
"	"	7783	0.38	1.56	2.08
"	"	6697	0.57	3.79	1.94
"	PLYMOUTH	13309	0.77	8.56	1.91
"	"	4691	0.24	1.75	3.85
"	PONTIAC	9408	0.61	3.87	5.31
"	"	8010	0.30	4.47	1.58
"	"	12682	0.41	2.75	1.63
"	DATSUN	13324	0.34	4.11	2.28
"	HONDA	6735	0.74	7.37	2.15
"	TOYOTA	7233	0.15	1.56	2.26
"	VW	4185	0.51	5.08	2.27
"	RABB	4392	0.32	5.75	2.77

Table E-2

FY 75 EFP data for 1975 California cars

Model Year	Make	Mileage	HC	CO	NOx
75	AMC	15859	0.44	6.70	1.86
"	BUICK	20125	0.98	15.05	1.93
"	"	28266	1.15	20.23	1.88
"	CADILLAC	41780	0.80	8.58	1.96
"	CHEVROLET	18750	1.04	5.67	1.84
"	"	8810	0.88	14.01	1.65
"	"	16086	0.50	2.48	2.49
"	"	4872	0.68	3.09	1.47
"	"	7781	1.06	5.68	1.04
"	CHRYSLER	16657	0.38	9.13	1.77
"	DODGE	17275	0.43	2.09	1.45
"	FORD	9688	0.27	1.67	1.39
"	"	3905	0.35	3.54	1.30
"	"	16173	0.91	17.73	0.86
"	"	24112	0.66	6.29	5.61
"	"	24207	1.15	24.97	0.94
"	MERCURY	11362	1.47	18.96	0.99
"	OLDSMOBILE	18298	0.65	2.75	1.69
"	"	12765	0.57	7.05	1.73
"	PLYMOUTH	6597	0.64	3.23	4.58
"	DATSUN	30479	0.42	4.30	2.06
"	TOYOTA	18381	0.25	2.76	1.60
"	"	10048	0.22	2.54	2.19
"	VW	11258	0.73	11.01	2.07
"	"	14026	0.33	1.88	2.43
"	PLYMOUTH	13507	0.47	11.11	1.24
"	PONTIAC	9635	0.68	3.22	1.50
"	"	22514	0.85	4.35	4.31

Table E-3

FY 74 and FY 75 data for 1976 California cars

Model Year	Make	Mileage	HC	CO	NOx
76	CAPR	1358	1.44	37.84	1.86
"	AMC	22508	.48	6.77	1.61
"	BUICK	3783	.65	10.47	1.64
"	"	25525	1.22	9.57	4.07
"	CADILLAC	9389	.70	5.79	1.37
"	CHEVROLET	5127	.49	3.04	1.36
"	"	2054	.80	7.16	1.38
"	"	5090	.93	16.08	1.32
"	"	15516	.63	2.35	1.54
"	"	7660	.96	12.57	1.51
"	"	2862	.67	6.31	1.51
"	"	4101	.41	3.39	1.47
"	DODGE	4023	.57	4.03	1.41
"	"	4565	.49	7.29	2.08
"	FORD	13506	.64	5.50	1.49
"	"	1582	.47	3.79	1.07
"	"	4793	1.21	7.28	1.27
"	"	13278	.27	5.99	3.52
"	"	763	.85	7.73	1.00
"	"	10120	.68	5.54	1.05
"	MERCURY	5256	.55	7.56	1.34
"	"	25044	.49	1.32	1.77
"	OLDSMOBILE	14263	.86	2.06	1.47
"	"	10870	.42	2.39	1.22
"	"	17083	.49	2.84	1.20
"	PLYMOUTH	2436	.86	6.25	1.32
"	"	9688	2.42	25.77	1.36
"	PONTIAC	5892	.72	8.43	1.42
"	"	18392	.62	4.65	1.89
"	DATSUN	3033	.36	3.88	1.93
"	"	6638	.59	7.40	1.86
"	TOYOTA	1033	.25	2.57	1.63
"	"	12135	.49	7.43	1.33
"	VW	2193	.61	11.63	1.26
"	"	4570	1.49	45.61	.61

EPA Model For Determining Future LDV Emission Rates

Definitions

DF = deterioration factor

E = emissions

Elo = emissions at low mileage

E50 = emissions at 50,000 miles

ok = cars which have emissions performance of certification cars

m = cars which are maladjusted

s = cars which have totally lost emissions control

Eok = emissions of "ok" cars

Em = emissions of "m" cars

Es = emissions of "s" cars

fm = fraction of model year vehicles which are "m"

fok = fraction of model year vehicles which are "ok"

fs = fraction of model year vehicles which are "s"

M = 10,000 miles

AOC = advanced oxidation catalyst system

3WC = three way catalyst systems

EGR = exhaust gas recirculation

Equations

$$DF = \frac{E50}{Elo}$$

$$fm + fok + fs = 1.0$$

Assumptions

(1) It is assumed that AOC will be employed to meet HC/CO/NO_x standards of .41/3.4/2.0 gpm.

(2) It is assumed that 3WC will be employed to meet standards of .41/3.4/1.0.

(3) It is assumed that the population of vehicles is divided in three classes, an "ok", "m" and "s" class.

AOC (.41/3.4/2.0)

The quantity fm + fs was estimated by looking at I/M failure rate data for Ford cars in Chicago. Ford data were used because Fords were generally equipped with the air pumps employed on AOC cars (not present on the other cars which show a higher failure rate). The failure rate of the Ford cars (about 8% per year) was assumed to equal fm + fs. Therefore:

fm + fs = .08 M

after 10 years fm + fs = .8

fok = 1- .8 M

fm/fs is assumed to be 5/3

or fm = .05 M and fs = .03 M

a. "ok" Cars

EPA data suggested that low mileage AOC cars targeted toward .41/3.4/2.0 run at emissions levels of about..25/1.9/1.5. With these low mileage emissions DF's of 1.6 for HC and 1.8 for CO will just allow manufacturers to pass certification for these pollutants. However, the DF for NO_x is assumed to be 1.1, following the trends of earlier model year vehicles and allowing the manufacturers to handily meet certification levels.

b. "m" Cars

For HC and CO it is projected that the low mileage emissions of a maladjusted car (limited adjustment is assumed) are 2.8 gpm for CO and .46 gpm for HC.

For NOx it is assumed that maladjustments which increase HC and CO will leave NOx emissions (Em(HC, CO)) at the "ok" level discussed above. However it is further assumed that maladjustments, tampering or deterioration to the EGR system used with AOC technology will raise NOx emissions (Em(NOx)) to a low mileage level of 4.2 gpm. It is assumed that 20 percent of cars that have reached 100,000 miles will have NOx maladjustments. The deterioration of all maladjusted cars is assumed to be the same as those of "ok" cars.

c. "s" Cars

This portion of the vehicle population is assumed to have essentially no emissions control capability. Because of this the low mileage emissions of these vehicles are very high, i.e., 7.6 gpm HC, 57.0 gpm CO and 7.0 gpm NOx. However, a "non-catalyst" DF of 1.1 is assumed for these cars, representing a substantial reduction in the HC and CO DF's which were used for "ok" and "m" cars. It should be noted that based on EPA restorative maintenance data a substantially larger portion of the fleet is assumed to be "s" cars for HC and CO than NOx. The ratio used here is 3 to 1.

Table E-4
HC Emissions

M	fm	Em	fok	Eok	fs	Es	fleet E(HC)
0	0	.46	1.0	.25	0	7.6	.25
1	.05	.51	.92	.28	.03	7.75	.52
2	.1	.56	.84	.31	.06	7.9	.79
3	.15	.61	.76	.34	.09	8.05	1.07
4	.2	.66	.68	.37	.12	8.2	1.37
5	.25	.71	.60	.40	.15	8.35	1.67
6	.3	.76	.52	.43	.18	8.5	1.98
7	.35	.81	.44	.46	.21	8.65	2.30
8	.4	.86	.36	.49	.24	8.8	2.63
9	.45	.91	.28	.52	.27	8.95	2.97
10	.5	.96	.20	.55	.30	9.1	3.32

Table E-5
CO Emissions

M	fm	Em	fok	Eok	fs	Es	fleet E(CO)
0	.00	2.8	1.0	1.9	.00	57	1.9
1	.05	3.25	.92	2.2	.03	58.1	3.93
2	.1	3.7	.84	2.5	.06	59.3	6.03
3	.15	4.15	.76	2.8	.09	60.4	8.19
4	.2	4.6	.68	3.1	.12	61.6	10.42
5	.25	5.05	.60	3.4	.15	62.7	12.71
6	.3	5.5	.52	3.7	.18	63.8	15.06
7	.35	5.95	.44	4.0	.21	65.0	17.49
8	.4	6.4	.36	4.3	.24	66.1	19.97
9	.45	6.85	.28	4.6	.27	67.2	22.52
10	.5	7.3	.20	4.9	.30	68.4	25.15

Table E-6
NOx Emissions

M	fm(NOx)	Em(NOx)	fm(HC,CO)	EM(HC,CO)	fok	Eok	fs	Es	fleet E(Nox)
0	0	4.2	0	1.5	1.00	1.5	0	7.0	1.5
1	.02	4.28	.05	1.53	.92	1.53	.01	7.14	1.64
2	.04	4.37	.1	1.56	.84	1.56	.02	7.28	1.79
3	.06	4.45	.15	1.59	.76	1.59	.03	7.42	1.94
4	.08	4.54	.2	1.62	.68	1.62	.04	7.56	2.09
5	.10	4.62	.25	1.65	.60	1.65	.05	7.70	2.25
6	.12	4.70	.3	1.68	.52	1.68	.06	7.84	2.41
7	.14	4.79	.35	1.71	.44	1.71	.07	7.98	2.58
8	.16	4.87	.4	1.74	.36	1.74	.08	8.12	2.75
9	.18	4.96	.45	1.77	.28	1.77	.09	8.26	2.93
10	.20	5.04	.50	1.80	.20	1.80	.10	8.40	3.11

d. Combined ACC Fleet Emissions

The combined fleet emissions effect was computed by assuming that there were essentially 3 subfleets, i.e., an "ok", an "m" and an "s" fleet all having emissions levels which change as a function of mileage. The size of each fleet, i.e. fok, fm and fs are assumed to change with the age of the fleet; the size of the maladjusted fleet growing while the well maintained ("ok") fleet shrinks. Effects of less than 10,000 miles were ignored.

Tables E-4, E-5, and E-6 detail the lifetime emissions estimated by this "model" for a model year's fleet emissions.

3WC (.41/3.4/1.0)

For 3-way catalyst systems it has been assumed that the use of electronics and exhaust gas sensors will substantially cut back on the proportion of cars in a model year fleet which will be maladjusted or totally lose their emissions control efficiency. In this instance fm + fs = .1 when M=10. It should also be noted that two types of maladjustments (or component failures) are assumed for the 3-way systems. In one case the maladjustment or failure is assumed to result in the catalyst seeing a lean air/fuel mixture; in the other case the catalyst would see a rich air/fuel mixture; for the 3WC then at M=10:

fok = 0.6; fl(lean)= 0.05; fr(rich) = 0.15; fs = 0.2; fm = fl + fr = 0.2

a. "ok" Cars

In the "model" it is assumed that coming off the assembly line all new cars will perform like manufacturer's cars in certification. At 100,000 miles it is assumed that 60 percent of the model year fleet will

perform at that level. These may be optimistic assumptions. However, lack of in-use data on 3WC cars prohibits any evaluation of this assumption.

To obtain an estimate of the "ok" emissions of 3WC cars, data on nine 3WC Volvos were reviewed:

3WC VOLVO DATA (50K RESULTS)

EPA AMA	.617	2.56	1.31
EPA AMA	.391	3.22	1.89
EPA AMA	.226	5.04	.51
Taxi	1.37	10.90	1.98
Taxi	.454	6.42	1.10
Taxi	.184	2.26	.69
Tire Test	.320	3.74	1.30
Tire Test	.208	3.45	.26
Tire Test	.381	3.42	.23
Ave Emissions	.45	4.56	1.09
Ave DF	1.8	1.4	3.5

Using these data for DF's but assuming that "ok" cars just meet the relevant emissions standards (.41/3.4/1.0) at 50,000 miles, the following DF's and low mileage emissions factors were developed for use in the model for "ok" cars.

DF	HC = 1.8	CO = 1.4	NO_x = 3.5
Low Mileage E	HC = .41/1.8 = .23	CO = 3.4/1.4 = 2.43	NO_x = 1.0/3.5 = .29

b. "m" Cars

The "m" portion of the model year fleet has been assumed to have two segments, the "r" and "l" (lean). The "l" segment is assumed to be those cars which experience an oxygen sensor failure. It is assumed that such a failure will result in the catalyst seeing a lean air/fuel mixture, slightly improving the oxidation of HC and CO, but eliminating the catalytic control of NO_x. Therefore, El for HC and CO are lower than Eok, but El for NO_x is considerably higher than Eok (El for NO_x does not reach Es because some EGR control is assumed even on 3WC systems). The assumed failure rate algorithm for oxygen sensors is essentially:

Avg. sensor life = 3 years

Probability of failure at age:

25% at 2 years

50% at 3 years

25% at 4 years

In any year 15% of sensors failed in that year will not have been replaced.

Using the assumptions above, the following DF's and low mileage emissions were estimated for E1:

DF	HC = 1.8	CO = 1.4	NOx = 1.1
Low Mileage E	HC = .2	CO = 2.0	NOx = 3.5

For "r" cars, the control efficiency for HC and CO drops from "ok" levels while it improves for NOx. It is assumed that over time the segment of the model year fleet with rich carburetion will increase linearly from 0 percent at the assembly line to 15% at 100,000 miles. In this rich operating mode emissions and DF's are estimated to be as follows:

DF	HC = 1.1	CO = 1.1	NOx = 3.5
Low mileage E	HC = 3.0	CO = 33	NOx = .25

c. "s" Cars

With one exception emissions of "s" cars are assumed to equal those described for the AOC case. However, because of the inherent durability and anti-tampering characteristics of electronics and the likely improvements in the driveability of 3WC cars (thereby leading to less desire to tamper), the proportion of the model year fleet assumed to be "s" cars has been dropped from the 30% figure at 100,000 miles as assumed in the AOC case to 20% at 100,000 miles.

As in the AOC case this portion is assumed grow linearly from 0% at the assembly line to 20% at 100,000 miles.

The one exception mentioned above is the division for HC and NOx of the "s" fleet into two subcategories. These subcategories "s (HC)" and "s(NOx)" are included to reflect the fact that an "s" car cannot simultaneously have both high emissions of HC and NOx. Therefore two categories are included here:

Es(HC) = emissions of a gross HC emitter

Es(NOx) = emissions of a gross NOx emitter

The ratio of fs(HC) to fs(NOx) is 3 to 1 as in the AOC case, reflecting EPA's belief that there are likely to be a larger number of gross HC emitters than gross NOx emitters.

As stated above Es(HC) for HC and Es(NOx) for NOx are identical to those set forth for "s" cars in the AOC case. However, new emissions factors have been developed for Es(NOx) for HC (the HC emissions possible for a gross NOx emitter) and Es(HC) for NOx (the NOx emissions possible from a gross HC emitter).

Es(HC) for NOx = 3.4 gpm at low mileage

Es(NOx) for HC = 4.0 gpm at low mileage

fs(HC) + fs(NOx) = .2 at M=10

fs(HC)/fs(NOx) = 3

The DF's are identical to the DF's for "s" cars in the AOC case.

d. Combined 3WC Fleet Emissions

The combined fleet emissions for 3WC systems are shown below.

TABLE E-7

HC Emissions

M	fl	El	fr	Er	fok	Eok	fs(HC)	Es(HC)	fs(NOx)	Es(NOx)	Fleet E(HC)
0	0	.20	0	3.0	1.0	.23	0	7.6	0	4.0	.23
1	0	.23	.015	3.06	.965	.27	.015	7.75	.005	4.08	.44
2	.04	.25	.03	3.12	.89	.30	.03	7.9	.01	4.16	.65
3	.075	.30	.045	3.18	.82	.34	.045	8.05	.015	4.24	.87
4	.047	.33	.06	3.24	.813	.37	.06	8.2	.02	4.32	1.09
5	.038	.36	.075	3.30	.787	.41	.075	8.35	.025	4.4	1.32
6	.058	.39	.09	3.36	.732	.45	.09	8.5	.03	4.48	1.55
7	.052	.42	.105	3.42	.703	.48	.105	8.65	.035	4.56	1.79
8	.045	.46	.12	3.48	.675	.52	.12	8.8	.040	4.64	2.03
9	.052	.49	.135	3.54	.633	.55	.135	8.95	.045	4.72	2.27
10	.050	.52	.15	3.60	.60	.59	.15	9.14	.05	4.8	2.52

TABLE E-8

CO Emissions

M	Fl	El	fr	Er	fok	Eok	fs	Es	Fleet E(CO)
0	0	2.0	0	33	1.0	2.4	0	57	2.4
1	0	2.16	.015	33.7	.965	2.6	.02	58.1	4.2
2	.04	2.32	.03	34.3	.89	2.75	.04	59.3	5.9
3	.075	2.48	.045	35.0	.82	3.0	.06	60.4	7.9
4	.047	2.64	.06	35.6	.813	3.2	.08	61.6	9.8
5	.038	2.80	.075	36.3	.787	3.4	.10	62.7	11.8
6	.058	2.96	.09	37.0	.732	3.55	.12	63.8	13.8
7	.052	3.12	.105	37.6	.703	3.7	.14	65.0	15.8
8	.045	3.28	.12	38.3	.675	3.9	.16	66.1	17.9
9	.052	3.44	.135	38.9	.633	4.1	.18	67.3	20.1
10	.050	3.60	.15	39.6	.60	4.25	.20	68.4	22.4

TABLE E-9

NOx Emissions

M	fl	El	fr	Er	fok	Eok	fs(NOx)	Es(NOx)	fs(HC)	Es(HC)	Fleet E(NOx)
0	0	3.5	0	.25	1.0	.29	0	7.0	0	3.4	.29
1	0	3.57	.015	.38	.965	.43	.005	7.14	.015	3.47	.51
2	.04	3.64	.03	.5	.89	.57	.01	7.28	.03	3.54	.85
3	.075	3.71	.045	.63	.82	.71	.015	7.42	.045	3.60	1.16
4	.047	3.78	.06	.75	.813	.86	.02	7.56	.06	3.67	1.29
5	.038	3.85	.075	.88	.787	1.0	.025	7.7	.075	3.74	1.47
6	.058	3.92	.09	1.0	.732	1.14	.03	7.84	.09	3.81	1.73
7	.052	3.99	.105	1.13	.703	1.29	.035	7.98	.105	3.88	1.92
8	.045	4.06	.12	1.25	.675	1.42	.04	8.12	.12	3.94	2.09
9	.052	4.13	.135	1.38	.633	1.57	.045	8.26	.135	4.01	2.31
10	.050	4.2	.15	1.50	.60	1.71	.05	8.4	.15	4.08	2.49

II. GASOLINE-POWERED LIGHT-DUTY TRUCKS

(a) 0-6000 lbs. LDTs

Emission rates for pre-1979 LDTs less than 6000 pounds were estimated from regression analyses of EFP data. The emission rate estimates for the 1970 and later model year LDTs (both the 0-6000 lb. and the 6001-8500 lb. categories) were based on the new standards which go into effect in 1979 for both weight categories. The 1979 and later model year LDTs were assumed to perform relative to their standards as did the 1975-1978 model year 0-6000 lb. LDTs relative to their standards. The deterioration rates for HC and CO in this (1979 and later) category are assumed to be the same as the 1975-1978 category since the same control technology would be used. The NOx deterioration rate is assumed to be half of the LDV NOx deterioration rate since HC and CO LDT deterioration rates are twice that of LDVs and NOx rates tend to decrease as HC and CO rates increase. This lower NOx rate reflects the expectation that although most of these trucks are catalyst equipped, some are non-catalyst trucks.

In 1983, all LDTs are assumed to be catalyst equipped and to have deterioration rates equivalent to LDVs. The post-1982 HC and CO initial emission rates (and the post - 1984 NOx rate) were determined by assuming that the ratio of the LDT initial emission rate to its standard is equal to the ratio of the appropriate LDV rate to its corresponding standard. Since the LDT hydrocarbon standard is 0.99 gm/mi, it must be compared to the 0.9 gm/mi HC standard for LDVs. This LDV standard has a corresponding initial emission rate of 0.29 gm/mi.

(b) 6001-8500 lb. LDTs

Test data from the medium duty truck baseline study ("Technical Evaluation of Emission Reduction Requirements for Vehicles Between 6000 and 14,000 pounds GVW", EPA-460/3-73-005) were used to obtain estimates of emission rates for pre-1970 model year LDTs. The mean emissions of the 6001-8500 lb. trucks tested in the baseline study are 10.86 gm/mi HC, 104.4 gm/mi CO, and 6.49 gm/mi NOx. The trucks were approximately an average of seven years old at the time of testing. Therefore the mean emissions are assumed to represent emission rates for seven year old 6001-8500 lb. LDTs. The deterioration rates for this group of LDTs are assumed to be equal to the deterioration rates of pre-controlled light-duty automobiles. The initial emission rates were determined by applying the deterioration rates to the age seven emission rates and working backwards.

Emission rates for 1970-1978 6001-8500 lb. LDT's were based on regression analyses of test data from 1970-1974 model year vehicles.

For the 1970 to 1978 model years the deterioration in gm/mi is assumed to be the same gm/mi quantity as that for controlled, precatalyst LDVs.

The 1979 and later model year LDTs in the 6001-8500 lb. category have the same emission standards, and therefore the same emission rates, as the 0-6000 lb. category.

III. GASOLINE POWERED HEAVY DUTY VEHICLES

Emission rates for pre-controlled through the 1974-1978 model year HDVs are based upon regression analysis of in-use vehicle test data.

The 1979 and later model year HDVs are assumed to perform relative to their standards as the 1974-1978 model year vehicles performed relative to their standards.

The deterioration rates through the 1979 model year are assumed to be equal to the deterioration rates of LDVs of corresponding control systems.

Post 1982 gasoline HDV emission rates were estimated using a "modeling" approach similar to the one used for future year LDV estimates. This approach is explained in the following section.

Derivation of Post-1982 HC and CO Exhaust Rates and Post-1984 NOx Exhaust Rates

Two methods, similar to those found in the previously presented light duty vehicle (LDV) "Analysis of Emission Factors for Future New Cars", were developed to compute the heavy-duty gasoline vehicle (HDGV) emission factors. These two methods were named the additive method and the multiplicative method. Both methods are explained and illustrated below.

BASIC ASSUMPTIONS

1) The 1983 standards for HDGVS are 2.85,29.7, and 5.35 grams per mile for HC, CO, and NOx respectively.
2) All 1983 and later model year HDGVs are assumed to be operating with advanced oxidation catalysts (AOC).
3) The 1983 standards for LDVs are .41, 3.4, and 1.0 grams per mile respectively. If only AOC technology were used, only a 2.0 gm NOx standard could be attained.
4) Emissions deterioration increases linearly with mileage accrual.
5) The "useful life" (as discussed in Section 202 of the Clean Air Act) of a HDGV is 80,000 (80k) miles.
6) The fraction of HDGVs that are malmaintained, have totally lost emission controls, or are meeting standards at 80K miles (Fm, Fs, and Fok) are assumed to be the same as the LDVs' Fm, Fs and Fok found in the previous LDV analysis.

Step 1 (OK Vehicles' starting values)

To find the initial, zero-mileage emission rate (E) (HDGV Eok, p,M=0) for each pollutant for both the additive and multiplicative methods, assume the ratio of the 1983 HDGV standard for ok vehicles to the LDV 1983 standard for ok vehicles equals the ratio of the HDGV starting value for ok vehicles to the LDV starting value for ok vehicles.

$$\frac{\text{HDGV Eok, p,M=0}}{\text{LDV Eok, p,M=0}} = \frac{\text{HDGV Eok, p,1983 standard}}{\text{LDV Eok, p,1983 standard}}$$

where:

HDGV Eok, p,1983 standard is from assumption 1

LDV Eok, p,1983 standard is from assumption 3

LDV Eok, p,M=0 is from previous "Analysis of Emission Factors for Future New Cars" in Section I above.

p Is the pollutant of interest

M=0 Signifies zero miles traveled

Step 2 (OK Vehicles' column values)

In repeating the methodology used in the "Analysis of Emission Factors for Future New Cars," the emission levels and fraction of vehicles in each category are determined for each pollutant as presented in Tables E-10 to E-15.

If we assume for both the additive and multiplicative methods that an ok vehicles just meets standards at 80k miles, and deterioration is linear with mileage, then the incremental change, (Delta Eok,p) can be

computed like so,

Delta HDGV Eok,p=((HDGV Eok, p,M=8) - (HDGV Eok,p,M=0))/8

Where:

HDGV Eok,p,M=8 — Is the 1983 standard, found in assumption 1.

HDGV Eok, p,M=0 — is the starting value computed in step 1 and all other notation is the same as in step 1.

Each starting value (HDGV Eok, p,M=0) is then incremented by delta HDGV Eok,p from M=1 to 10. These values comprise the ok column for each pollutant for each method in Tables E-10 to E-15.

Step 3 (M and S vehicles' starting values and column values)

To determine the starting values for malmaintained HDGVs (HDGV Em, p,M=0) and vehicles that have totally lost emission controls (HDGV Es, p,M=0), Step 3 is divided into two sections. Section 3a will contain the methodology for HC and CO, and section 3b will contain the methodology for NOx.

Section 3a (M and S vehicles, HC and CO)

To find the starting values (HDGV Em,p,M=0) and the increment of deterioration (delta HDGV Em,p) for the malmaintained vehicles for HC and CO. Assume the ratio of the starting value for ok malmaintained HDGVs (HDGV Em,p,M=0) to the starting value for ok HDGVs (HDGV Eok,p,M=0) was equal to the ratio of the starting value for malmaintained LDVs (LDV Em,p,M=0) to the starting value for ok LDVS (LDV Eok,p,M=0)

$$\frac{\text{HDGV Em,p,M=0}}{\text{HDGV Eok,p,M=0}} = \frac{\text{LDV Em,p,M=0}}{\text{LDV Eok,p,M=0}}$$

where:

HDGV Eok,p,M=0	Was computed in step 1
LDV Em,p,M=0	Is from the previous LDV analysis
LDV Eok,p,M=0	Is from the previous LDV analysis
p	Is the pollutant of interest (HC or CO)

For the additive method, the increment of deterioration (Delta HDGV, Em,p) was assumed to be the same as the increment of deterioration for ok HDGVs (Delta HDGV Eok,p). This value was calculated in step 2. Thus, for the additive method, the Em column was created by simply incrementing the starting value by Delta HDGV Eok,p through M=1-10.

For the multiplicative method the deterioration increment (Delta HDGV Em,p) was computed differently. First, it was assumed the ratio of the 80k mile value for malmaintained vehicles (HDGV Em,p,M=0) was equal to the ratio of the 80k mile value for ok vehicles (HDGV Eok,p,M=8) to the starting value for ok vehicles (HDGV Eok,p,M=0).

$$\frac{\text{HDGV Em,p,M=8}}{\text{HDGV Em,p,M=0}} = \frac{\text{HDGV Eok,p,M=8}}{\text{HDGV Eok,p,M=0}}$$

Where:

HDGV Eok,p,M=8	Is from assumption 1
HDGV Eok, p,M=0	Was computed in Section 1
p	Pollutant of interest (HC or CO)

Once the 80k mile figure was found, the increment of deterioration (delta HDGV Em,p) was computed and used just like the increment of deterioration for ok HDGVs in step 2.

HDGVs that have totally lost emission controls are assumed to deteriorate at the following precontrol levels as presented in the Mobile Source Emission Factors final document, March 1978:

23.90 g/mi	HDGV Es,HC,M=0
0.58 g/mi	Delta Es,HC
272.90 g/mi	HDGV Es,CO,M=0
3.06 g/mi	Delta Es,CO

So far for Tables E-10 to E-15, we have filled in columns Fok,Fm, and Fs for all pollutants and all methods by using assumption 6. We have filled in columns Eok, Em, and Es for both HC and CO for both the multiplicative and additive methods, and we have filled in the Eok column for both methods for NOx.

Section 3b (M and S vehicles, NOx)

The remaining columns are the Em columns and the Es columns for NOx. Since the LDV analysis separated malmaintained NOx into two categories, the same is done for HDGVs. The first category will be called HDGV Em, HC/CO for the situation in which maladjustment will increase HC and CO and will not affect NOx emissions to any great extent. The second category will be called HDGV Em,NOx for the situation in which the EGR system has deteriorated or has been subjected to tampering, which will increase NOx emissions.

Section 3b, Category 1 (HDGV Em,HC/CO)

For the HDGV Em,HC/CO category, the column entries for NOx equal the HDGV Eok column entries for both the additive and multiplicative case.

Section 3b, Category 2 (HDGV Em,NOx)

The NOx value for all vehicles which have lost all emission controls (HDGV Es, NOx) is assumed constant for the life of the vehicle. This value is 12.80 grams per mile, as found for the years 1970-1973 in the Mobile Source Emission Factor document.

For both the additive and multiplicative methods, it was assumed that the ration of the starting value for malmaintained HDGVs with EGR malfunctions (HDGV Em, NOx,M=0) to the starting value for HDGVs that have lost all emission controls (HDGV Es NOx,M=0) is equal to the ratio of the starting value for malmaintained LDVs with EGR malfunction (LDV Em,NOx,M=0) to the starting value for LDVs which have totally lost emission controls (LDV Es,NOx,M=0).

$$\frac{\text{HDGC Em,NOx,M=0}}{\text{HDGV Es,NOx,M=0}} = \frac{\text{LDV Em,NOx,M=0}}{\text{LDV Es,NOx,M=0}}$$

Where

HDGV Es,NOx,M=0	Is 12.80 as discussed above
LDV Em,NOx,M=0	Is from the previous LDV section
LDV Es,NOx,M=0	Is from the previous LDV section

For the additive method, the increment of deterioration for malmaintained HDGVs with EGR failure (Detla HDGV Em,NOx) was assumed to be equal to the ok JDGV NOx deterioration increment. The column entries for M=1-10 were then computed as in step 2.

The multiplicative method for computing the column entries is the same as in Section 3a.

Tables E-10, E-11 and E-12 are the additive method tables for HC,CO and NOx respectively. Tables E-13, E-14, and E-15 are the multiplicative method tables for HC, CO, and NOx respectively.

Results of Analysis

Once the composite fleet deterioration factors (E(P))P=HC,CO,NOx) had been computed, regression analysis were performed with the 10k mileage increments (E(P) values vs M values). Figures E-1, E-2 and E-3 are graphs showing the regression lines, regression equations, correlation coefficients, and F-scores for HC, CO and NOx, respectively, for both the additive and multiplicative methods. As can be seen, all regressions are significant at the 95% confidence interval. Also, there is very little difference between the two methods in the 0 to 100k mile interval.

It should be noted that a better fit for the data could be found with a quadratic model ($y = a+bx+cx^2$). However, because the differerences between the R values for the linear and quadratic models were small, and for the sake of simplicity, the linear model is used. In order to be consistent with the multiplicative method used to derive the LDV emission rates for future new cars, the multiplicative method was also used to derive the future HDGV exhaust emission rates.

TABLE E-10

Heavy Duty Gas Vehicles
HC
Additive Method

M	Eok	Fok	Em	Fm	Es	Fs	E(HC)
0	1.74	1.00	3.20	0.00	23.90	0.00	1.74
1	1.88	0.92	3.34	0.05	24.48	0.03	2.63
2	2.02	0.84	3.48	0.10	25.06	0.06	3.55
3	2.16	0.76	3.62	0.15	25.64	0.09	4.49
4	2.30	0.68	3.76	0.20	26.22	0.12	5.46
5	2.44	0.60	3.90	0.25	26.80	0.15	6.46
6	2.58	0.52	4.04	0.30	27.38	0.18	7.48
7	2.72	0.44	4.18	0.35	27.96	0.21	8.53
8	2.84	0.36	4.32	0.40	28.54	0.24	9.60
9	2.98	0.28	4.46	0.45	29.12	0.27	10.70
10	3.12	0.20	4.60	0.50	29.70	0.30	11.83

Where:

F = fraction

E = emissions level in grams per mile

M = mileage in 10,000 mile increments

TABLE E-11

Heavy Duty Gas Vehicles
CO
Additive Method

M	Eok	Fok	Em	Fm	Es	Fs	E(CO)
0	16.60	1.00	24.47	0.00	272.90	0.00	16.60
1	18.24	0.92	26.11	0.05	275.96	0.03	26.37
2	19.88	0.84	27.75	0.10	279.02	0.06	36.22
3	21.51	0.76	29.38	0.15	282.08	0.09	46.14
4	23.15	0.68	31.02	0.20	285.14	0.12	56.16
5	24.79	0.60	32.66	0.25	288.20	0.15	66.27
6	26.43	0.52	34.30	0.30	291.26	0.18	76.46
7	28.07	0.44	35.93	0.35	294.32	0.21	86.73
8	29.70	0.36	37.57	0.40	297.38	0.24	97.09
9	31.35	0.28	39.21	0.45	300.44	0.27	107.54
10	32.98	0.20	40.85	0.50	303.50	0.30	118.01

TABLE E-12

Heavy Duty Gas Venicles
NOx
Additive Method

M	Eok	Fok	Em,HC/CO	Fm,HC/CO	Em,NOx	Fm,NOx	Es	Fs	E(NOx)
0	4.01	1.00	4.01	0.00	7.68	0.00	12.80	0.00	4.01
1	4.18	0.92	4.18	0.05	7.85	0.02	12.80	0.01	4.35
2	4.34	0.84	4.34	0.10	8.02	0.04	12.80	0.02	4.66
3	4.51	0.76	4.51	0.15	8.18	0.06	12.80	0.03	4.98
4	4.68	0.68	4.68	0.20	8.35	0.08	12.80	0.04	5.30
5	4.85	0.60	4.85	0.25	8.52	0.10	12.80	0.05	5.61
6	5.01	0.52	5.01	0.30	8.69	0.12	12.80	0.06	5.92
7	5.18	0.44	5.18	0.35	8.85	0.14	12.80	0.07	6.23
8	5.35	0.36	5.35	0.40	9.02	0.16	12.80	0.08	6.53
9	5.52	0.28	5.52	0.45	9.19	0.18	12.80	0.09	6.83
10	5.69	0.20	5.69	0.50	9.36	0.20	12.80	0.10	7.14

TABLE E-13

Heavy Duty Gas Vehicles
HC
Multiplicative Method

M	Eok	Fok	Em	Fm	Es	Fs	E(HC)
0	1.74	1.00	3.20	0.00	23.90	0.00	1.74
1	1.88	0.92	3.46	0.05	24.48	0.03	2.64
2	2.02	0.84	3.71	0.10	25.06	0.06	3.57
3	2.16	0.76	3.97	0.15	25.64	0.09	4.54
4	2.30	0.68	4.23	0.20	26.22	0.12	5.56
5	2.44	0.60	4.48	0.25	26.80	0.15	6.60
6	2.58	0.52	4.74	0.30	27.38	0.18	7.69
7	2.72	0.44	4.99	0.35	27.96	0.21	8.81
8	2.84	0.36	5.25	0.40	28.54	0.24	9.97
9	2.98	0.28	5.51	0.45	29.12	0.27	11.18
10	3.12	0.20	5.76	0.50	29.70	0.30	12.41

TABLE E-14

Heavy Duty Gas Vehicles
CO
Multiplicative Method

M	Eok	Fok	Em	Fm	Es	Fs	E(CO)
0	16.60	1.0	24.47	0	272.90	0	16.60
1	18.24	.92	26.88	.05	275.96	.03	26.40
2	19.88	.84	29.30	.1	279.02	.06	36.37
3	21.51	.76	31.71	.15	282.08	.09	46.49
4	23.15	.68	34.13	.2	285.14	.12	56.78
5	24.79	.60	36.54	.25	288.20	.15	67.23
6	26.43	.52	38.95	.3	291.26	.18	77.86
7	28.07	.44	41.37	.35	294.32	.21	88.64
8	29.7	.36	43.78	.4	297.38	.24	99.58
9	31.35	.28	46.19	.45	300.44	.27	110.68
10	32.98	.20	48.61	.5	303.50	.30	121.95

TABLE E-15

Heavy Duty Gas Vehicle
NOx
Multiplicative Method

M	Eok	Fok	Em,HC/CO	Fm,HC/CO	Em,NOx	Fm,NOx	Es	Fs	E(NOx)
0	4.01	1.00	4.01	0.00	7.68	0.00	12.80	0.00	4.01
1	4.18	0.92	4.18	0.05	8.00	0.02	12.80	0.01	4.35
2	4.34	0.84	4.34	0.10	8.32	0.04	12.80	0.02	4.67
3	4.51	0.76	4.51	0.15	8.64	0.06	12.80	0.03	5.01
4	4.64	0.68	4.68	0.20	8.97	0.08	12.80	0.04	5.35
5	4.85	0.60	4.35	0.25	9.29	0.10	12.80	0.05	5.69
6	5.01	0.53	5.01	0.30	9.61	0.12	12.80	0.06	6.03
7	5.18	0.44	5.18	0.35	9.93	0.14	12.80	0.07	6.38
8	5.35	0.36	5.35	0.40	10.25	0.16	12.80	0.08	6.73
9	5.52	0.26	5.52	0.45	10.57	0.18	12.80	0.09	7.08
10	5.69	0.20	5.69	0.50	10.89	0.20	12.80	0.10	7.45

IV. DIESEL POWERED HEAVY-DUTY VEHICLES

Emission rates for diesel HDVs for 1978 and earlier model years were determined from linear regression of emissions on mileage from in-use vehicle test data. Since diesel HDVs have zero deterioration, the mean emissions of the in-use test vehicles are used as the emission rates.

The 1979-1982 HC and CO rates are assumed to equal the 1974-1978 rates since they would still be below standards. The 1979-1984 NOx rate is assumed to be equal to the 1979 interim standard of 19.9 gm/mi.

Post-1982 CO rates are assumed not to change since they are already below standards. The post-1982 HC rate and the post-1984 NOx rate are assumed to be equal to their respective standards.

V. MOTORCYCLES

Uncontrolled (Pre-1978) Motorcycles

Emission test results from approximately 100 motorcycles (a combination of EPA in-house, manufacturer, and contractor tests) provide the data used to characterize the emissions from uncontrolled motorcycles.

The emission deterioration rates per 10,000 miles of uncontrolled motorcycles are assumed to be the same as LDV rates for corresponding control technologies.

1978-1979 Model Years

The first federal standards for motorcycles range from 8 to 22.4 gm/mi HC depending upon engine size; they apply to the 1978-1979 model year vehicles. The low mileage emission levels for motorcycles subject to 1978 standards are assumed to remain at pre-controlled levels for all categories of motorcycles which have uncontrolled emissions below the 1978 standards. The other categories having emission levels which are

above the 1978 standards are assumed to perform relative to the 1978 standard in the same proportion as the controlled pre-catalyst LDVs performed relative to their standard. Therefore, low mileage emissions for these categories are 64 percent of the HC standard and 76 percent of the CO standard. The NOx low mileage emissions are assumed to increase 100 percent over the uncontrolled levels, and still remain well below the LDV level.

The deterioration rates per 10,000 miles for the 1978-1979 model year motorcycles are assumed to be the same as the controlled pre-catalyst LDV deterioration rates.

1980-1982 Model Year Motorcycles

The low mileage emissions of motorcycles controlled to the 1980 standards were assumed to be equal to uncontrolled or 1978-1979 model year motorcycle emissions if the pre-1980 model year vehicle emissions were below the 1980 standards. The other categories of motorcycles (with pre-1980 model year venicle emissions greater than the 1980 standard) are assumed to change in the same proportion as the 1978-1979 model year vehicles. That is, the low mileage HC and CO values are 64 percent and 76 percent of their respective standards, while NOx emissions are increased 100 percent over 1978-1979 model year venicle levels.

The deterioration rates for the 1980-1982 model year motorcycles are assumed to equal the deterioration rates of the 1978-1979 model year motorcycles.

1983 and Later Model Year Motorcycles

HC and CO emission rates for motorcycles built to the 1983 standards are assumed to have the same deterioration rates as LDVs of corresponding control technology, and to have initial emission rates which are the same ratio of their standards as are LDV emission rates to their standards for corresponding model years and control technologies.

APPENDIX E

PART TWO: DERIVATION OF EXHAUST EMISSION RATES FOR CALIFORNIA VEHICLES

(For All California Vehicles, Consult The Preceeding Section Of This Appendix In Addition To The Following Comments.)

I. CALIFORNIA LIGHT-DUTY GASOLINE POWERED VEHICLES (AUTOMOBILES)

Pre-controlled Vehicles (Pre-1966 Model Years)

The pre-1966 model year LDVs in California were subject to the same standards as were the pre-1968 model year 49-state vehicles. Therefore the emission rates for the pre-1966 California LDV's are assumed to equal low-altitude pre-1968 LDV emission rates.

Pre-catalyst Controlled Vehicles (1966-1974 Model Years)

The HC and CO initial emission rates and deterioration rates are the intercepts and slopes of lines fitted to the mean emissions versus mean mileage plots of each model year sample of 1966-1974 Los Angeles vehicles tested in the FY'71 through FY'75 Emission Factor Programs (EFP). The NOx plots indicate that 1973-1974 model year California LDVs have a significantly lower initial emission rate than do the 1966-1972 California LDVs. The NOx initial emission rates for these categories equal the mean NOx measurements of all 1966-1972 and all 1973-1974 model year LDVs tested in the California FY'71 - FY '75 EFP.

1975-1976 Model Years

The initial emission rates and deterioration rates of 1975-1976 California LDVs were estimated from the regression lines through plots of emissions versus mileage measurements from all 1975 vehicles tested

in Los Angeles in the FY '74 and FY '75 EFP.

1977 and Later Model Years

See explanation in preceding 49-state LDV section. The post-1976 HC initial emission rate is slightly higher than the corresponding rate for other LDVs since California has a non-methane HC standard; while these rates are given as total HC.

II. CALIFORNIA LIGHT-DUTY TRUCKS

The California pre-1975 LDT emission rates are assumed to equal the emission rates of the model years and weight categories of 49-state LDTs with corresponding stanards and control technologies.

For other years, the 0-4K and 4-6K truck standards were averaged to get a composite class standard for 0-6K trucks. (About half of these trucks are imports less than 4K.) For each model year 0-6K trucks, the LDT standard was multiplied by the ratio of the appropriate LDV standards and the LDV in-use equations to get an adjusted intercept and slope. For 1978 LDTs the corresponding LDV standards are the 1975 California LDV standards. For 1979 LDTs, the appropriate LDV standards are the 1977 California standards. For 1981 and later the appropriate standards are the 1980 California LDV standards.

All 6-8.5K trucks were assumed to fall into the 0-6K inertia weight class, and the same procedure was followed as described above. For 1978-1980, the comparable LDV standards are 1975 California standards. For 1981, the comparable stancards are the 1980 California standards.

III. CALIFORNIA GASOLINE POWERED HEAVY-DUTY VEHICLES

Pre-1975 heavy-duty California vehicle emisssion rates are assumed to equal 49-state HDV emission rates for vehicles subject to similar

standards. The 1970 and 1974 49-state standards went into effect in 1969 and 1973 in California. The California HDV emission rates reflect this shift in the introduction of standards. The 1975-1976 California HDV emission rates are estimated from tests of in-use trucks. The 1977 and later model year HDVs in California are assumed to perform like the corresponding post-78 49-state HDVs, depending upon the applicable standards and control technologies.

IV. CALIFORNIA DIESEL POWERED HEAVY-DUTY VEHICLES

California diesel-powered HDV emission rates are assumed to equal the emission rates of the corresponding 49-state diesel HDVs.

V. CALIFORNIA MOTORCYCLES

The California motorcycle emission rates are assumed to equal the 49-state motorcycle rates for vehicles with similar standards and control technologies.

APPENDIX E

PART THREE: DERIVATION OF EXHAUST EMISSION RATES FOR HIGH-ALTITUDE VEHICLES

I. HIGH-ALTITUDE LIGHT-DUTY VEHICLES (AUTOMOBILES)

Pre-Controlled Vehicles (Pre-1968 Model Years)

The mean emissions of each model year sample of pre-1968 Denver vehicles tested in the FY '71 through FY '74 Emission Factor Programs (EFP) were plotted against the mean mileages of the same samples. Linear regression techniques were used to estimate the zero mileage emission rate (intercept of the line) and deterioration rates (slope or rate of change of the line) associated with the plots. The CO initial emission rate and the CO deterioration rate (in gm/mi per year) for the pre-1968 vehicles is equal to the intercept and slope of the estimated line through the plotted data. The HC plot and regression analysis were biased by a few extremely high mean HC emissions. When the extreme values were removed the high-altitude HC deterioration rate of pre-1968 test vehicles appeared to be approximately the same percent of its initial emission rate as the pre-1968 low-altitude, LDV deterioration rate is of its initial emission rate. Therefore, the tabled high-altitude deterioration rate for HC is set equal (in terms of percent of its initial emission rate) to the low-altitude deterioration rate of pre-controlled LDVs. The initial HC emission rate was determined by assuming that the ratio of initial HC emission rates of high-altitude LDVs/low-altitude LDVs equals the ratio of mean HC emissions of high-altitude LDVs/low-altitude LDVs as measured in the FY '71 EFP. The NOx deterioration rate

for high-altitude LDVs in this category is assumed to equal zero based upon the regression analysis and plots described above. The initial NOx emission rate is the mean of the NOx measurements from all pre-controlled vehicles tested in the Denver FY '71 - FY '74 EFP.

Pre-Catalyst Controlled Vehicles (1968-1974 Model Years)

The HC and CO initial emission rates and deterioration rates are the intercepts and the slopes of lines fitted to the mean emissions versus mean mileage plots of each model year sample of 1968-1974 Denver vehicles tested in the FY '71 through FY '74 EFP. A similar plot of 1968-1974 mean NOx emissions versus mean mileage indicated that the deterioration rate of NOx mean emissions over mileage is zero. The 1973-1974 model year vehicles exhibited an initial emission rate which was significantly lower than the 1968-1972 model year vehicles. Thus this category of vehicles was subdivided into two NOx groups; the 1968-1972 model years and the 1973-1974 model years. The initial NOx emission rates for vehicles in these two categories are the composite mean NOx measurements of all 1968-1972 and all 1973-1974 model year automobiles tested in the Denver FY '71 - FY '74 EFP.

1975-1976 Model Year Vehicles

Linear regression of the emissions on mileages measured on all the 1975 Denver automobiles tested in the FY '74, and FY '75 EFPs were used to estimate the HC, CO and NOx initial emission rates for the 1975-1976 high-altitude LDVs. Deterioration rates are assumed to be the same as at low-altitudes.

1977 Model Year Vehicles

High-altitude regulations applied to the 1977 model year vehicles, resulting in lower emission rates for HC and CO, as demonstrated by the results of EPA's EFP tests of 1977 model year vehicles in Denver.

The deterioration rate is the same as for the low-altitude 1975-1976 vehicles.

1978 and 1979 Model Years

The 1977 high-altitude regulations were suspended by the Clean Air Act Amendments passed in August 1977, thereby permitting 1978 and 1979 model year vehicles to emit at higher levels; assumed to be the same levels as 1975-1976 venicles.

1980 Model Year

Since the same vehicles in-use at low-altitudes will be in-use at high-altitudes and emitting at a different rate, the low-altitude in-use levels were increased by a ratio factor (75 Denver/75 low-altitude intercept values). The deterioration rate at high-altitudes is assumed to be the same as the deterioration rate at low altitudes.

1981-1983 Model Years

A similar ratio calculation was performed, e.g.,

81 Hi-alt. = (75 Hi-alt./74 Low-alt.) (81 Low-alt.)

1984 and Later

High-altitude values are equivalent to low-altitude values.

II. HIGH-ALTITUDE LIGHT-DUTY TRUCKS

A. Less Than 6000 lb. LDTs

Pre-1968 and 1968-1974 Model Year Vehicles

Prior to the 1975 model year, all LDTs, in the 0-6000 lb. category were subject to the same standards as were the pre-1975 light-duty automobiles. Therefore the emission rates for the pre-1975 model year LDTs are equal to the emission rates of LDVs of the same model year.

1975-1976 Model Years

Linear regressions of emissions on mileage measured on all the 1975 Denver LDTs tested in the FY '74 EFP were used to estimate the initial emission rates and deterioration rates for the 1975-1976 high-altitude LDTs in the 0-6000 lb. group.

1977 Model Year

High-altitude regulations apply to 1977 model year LDTs in the 0-6000 lb. weight category. Therefore the high-altitude emission rates for this group of LDTs are equal to the emission rates of low-altitude LDTs of the same model year and weight category.

1978 Model Year

As with LDVs, the 1977 high-altitude regulation was suspended, permitting LDTs to emit at a higher level in 1978. Emissions are assumed to revert to 1975-1976 levels.

1979-1982 Model Years

New LDT emission standards in 1979 will result in lower emission rates than in preceding years, but higher rates at high-altitudes than at low-altitudes (Hi-Alt LDV/Low-Alt LDV = High-Alt LDT/Low-Alt LDT for corresponding years).

B. LDTs Between 6000 lbs. and 8500 lbs.

Pre-1970 and 1970-1978 Model Year Vehicles

The pre-1970 and 1970-1978 model year groups of high-altitude 6001-8500 lb. LDTs are assumed to perform relative to low-altitude LDTs of the same model years as the high-altitude LDVs perform relative to the low-altitude LDVs with similar emission control systems. The 1970-1978 LDTs are assumed to have essentially equivalent control systems to those of the 1968-1974 LDVS. The pre-1970 model year 6001-8500 lb. trucks are uncontrolled and therefore the ratio of the emission rates of high to low-altitude pre-1968 LDVs is applied to determine the truck emission rates. The deterioration rates for the high-altitude trucks equal the deterioration rates in gm/mi of high-altitude LDVs with similar control systems.

1979 and Later Model Year Vehicles

The emission rates of 6001-8500 lb. high-altitude LDTs in this model year group equal the emission rates of the under 6000 lb. LDTs due to equivalent emission standards.

III. HIGH-ALTITUDE, HEAVY-DUTY VEHICLES (GASOLINE AND DIESEL)

The initial emission rates of high-altitude HDVs of any emission control group are assumed to be the same ratio of the initial emission rates of low-altitude HDVs with equivalent control systems as are the initial emission rates of high to low-altitude LDVs with similar control systems. The pre-1970 gasoline-powered HDVs and the pre-1974 diesel-powered HDVs are uncontrolled and are therefore compared to pre-1968 LDVs. The 1970-1973, 1974-1978, and 1979-1982 heavy-duty gasoline vehicles as well as the 1974-1978 and 1979-1982 heavy-duty diesel vehicles are assumed

to be controlled in a manner similar to 1968-1974 model year LDVs. 1983 HDVs (for HC and NOx; 1984 for NOx) are assumed to be catalytically controlled and, therefore, are assumed to be the same ratio of low-altitude 1983 HDVs as are the rates of 1975 high-altitude LDVs to 1975 low-altitude LDVs. 1984 and later HDVs at high-altitudes will be required to perform as well as HDVs at low-altitudes, therefore, their rates are equivalent.

IV. HIGH-ALTITUDE MOTORCYCLES

The high-altitude motorcycles of any control system are assumed to perform relative to low-altitude motorcycles with similar control the same as high-altitude LDVs perform relative to low-altitude LDVs. The pre-1968 model year motorcycles are uncontrolled and are compared to pre-1968 LDVs. The 1968-1974 LDV initial emission rate ratios are applied to the initial emission rates of the 1978-1979 and 1980-1982 model year groups of motorcycles. The 1983 model year high-altitude motorcycle rates are assumed to be the same ratio of low-altitude motorcycles rates as the ratio of 1975 high-altitude LDVs are to 1975 low-altitude LDVs. In 1984 motorcycles will be required to perform as well as high-altitudes as at low-altitudes. Therefore the 1984 and later model year motorcycles have the same emission rates as 1983 low-altitude motorcycles.

APPENDIX E

PART FOUR: DERIVATION OF IDLE EMISSION RATES

I. Low-altitude light-duty Automobiles

The idle emission deterioration rates, in terms of percent of initial idle emissions, for each control group of low-altitude LDV's are assumed to be equal to the percent FTP deterioration rates for the same control group.

The initial idle emission rates for the pre-controlled through 1975-79 model year LDV's were derived from the emission results of vehicle tests conducted in the FY '71, FY '73, and FY '74 EFP. The mean idle emission rates and mean mileage for each control category were calculated from the EFP test data. The initial idle emission rates were determined by applying the deterioration rates to the mean idle values at the mean test mileage and working backwards to the zero mileage point.

The post-1979 LDV categories for HC and CO (and the post-80 NOx category) are assumed to perform relative to the 1975-79 LDV category on the idle test in the same way as these categories perform in relation to one another on the FTP exhaust tests. For example, the initial idle HC emission rates of the 1980+ LDV's were determined by assuming that the ratio of initial idle rates of 1980 and later LDV's/1975-1979 LDV's is equal to the ratio of initial FTP rates of 1980+ LDV's/1975-79 LDV's.

II. Low-altitude Light-duty Trucks (0-6000 pounds)

The deterioration rates, as a percent of initial idle emission rates, for all model year categories of the 0-6000 pound LDT's are assumed to equal the percent deterioration rates of FTP emissions for vehicles of the same model year and weight category.

The idle emission rates of the pre-1968 and 1968-1974 model year LDT's in the 0-6000 pound category are equal to the LDV idle emission rates of the same model year group since these LDT's and LDV's are subject to the same standards.

The initial idle emission rates for the 1975-1978 model year LDT's in the 0-6000 pound group were determined from the mean emissions of a sample of 1975 trucks tested in the FY '74 EFP. The initial idle emission rates were calculated by applying the deterioration rates to the mean emissions at the mean test mileage and working backwards to zero mileage.

The initial idle emissions of the 0-6000 pound LDT's in the post-1978 model years were determined by assuming, for example, that the ratios of initial idle rates of 1979-1982 LDT's/1975-1978 LDT's are equal to the ratios of initial FTP rates of 1979-1982 LDT's/1975-1978 LDT's in the 0-6000 pound group.

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6001-8500 Pound Trucks

The initial idle emission rates of the pre-1970 and 1970-1978 model year LDT's in the 6001-8500 pound category were determined by the following ratios. The ratios of the initial idle rates of pre-1970 LDT's/pre-1968 LDV's are assumed to equal the ratios of initial FTP emissions of the same categories of vehicles. The ratios of the initial idle emissions of 1970-1978 LDT's/pre-1970 LDT's are considered to equal the ratios of initial FTP emissions of the same categories of vehicles.

The idle deterioration rates in gm/min for the pre-1970 and the 1970-1978 LDT's in the 6001-8500 pound category are equal to the idle deterioration rates of the pre-1968 and the 1968-1974 LDT's in the 0-6000 pound category.

The idle emission rates of the post-1978 LDT's in the 6001-8500 pound group are equal to the idle emission rates of the post-1978 LDT's in the 0-6000 pound group since these trucks are subject to the same controls.

III. Low-altitude Heavy-duty Vehicles (Gasoline-Powered)

The idle deterioration rate in gm/min for the HD gas vehicles in the pre-1970 and the 1970-1978 model years are equal to the gm/min deterioration rate of the pre-1968 and 1968-1974 LDV's, respectively.

A sample of gasoline-powered HDV's in the pre-1970, 1970-1973, and 1974-1978 model year categories were tested. The mean idle emissions of these test vehicles were used to determine the initial idle emission rates by applying the idle deterioration rates and working backwards from the age at time of test to age zero. The age at time of test was determined by comparing the average mileage of the sample vehicles to the accumulated annual miles driven and the corresponding age given in AP-42, Supplement 5 for gasoline powered HDV's.

The initial idle rates of the 1979 and later gasoline-powered HDV's were derived by assuming that the ratios of initial idle rates of each model year category HDV's to 1974-1978 HDV's are equal to the ratios of initial FTP rates of the same categories of vehicles.

The idle deterioration rates in gm/min for the 1979 and later model year HDV groups are assumed to be the same ratio to initial idle rates as the FTP deterioration rates are to initial FTP rates for the same control group.

IV. Low-altitude Diesel-Powered Heavy-duty Vehicles

The idle deterioration rates are assumed to equal zero for all model years. The pre-1974 and the 1974-1978 model year diesel HDV idle emission rates equal the mean emissions of sample vehicles tested.

The initial idle rates of the 1979 and later HDV's were calculated by assuming that the ratios of initial idle rates of 1979 and later HDV's/1974-1978 HDV's equal the ratios of initial FTP rates of the same categories of HDV's.

V. Low-altitude Motorcycles

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The initial idle emission rates for motorcycles were determined by the following ratios. The ratios of initial idle emissions of the pre-1978 motorcycles/pre-1968 LDV's, 1978-1979 motorcycles/pre-1978 motorcycles, 1980-1982 motorcycles/1978-1979 motorcycles, and 1983+ motorcycles/1980-82 motorcycles are equal to ratios of the initial FTP emissions for the same categories of vehicles.

The idle deterioration rates, in percent of initial idle emissions, for all categories of motorcycles are assumed equal to the ratio of exhaust deterioration rates to initial exhaust rates for the same categories of motorcycles.

VI. High-altitude Light-duty Automobiles

The idle deterioration rates, expressed in percent of initial idle emissions, for any control category of LDV's equal the percent FTP deterioration rates of the same control category.

The initial idle emissions of high-altitude pre-controlled through 1976 model year LDV's were derived from mean estimates of samples of Denver vehicles tested in the FY '71, FY '73, and FY '74 EPA. The initial rates were derived from the mean values by the same method described for low-altitude LDV's.

The idle emission rates of high-altitude LDV groups between 1977 and 1983 model years are assumed to be the same ratio to their respective low-altitude LDV idle rates as the ratio of those high-altitude exhaust rates to low-altitude exhaust rates for the corresponding model year groups.

The 1984+ high-altitude LDV idle emission rates are assumed equal to the low-altitude LDV idle emission rates of the same model year due to the existence of high-altitude regulations.

VII. Other High-altitude Vehicle Categories

The idle emission rates for all other categories of high-altitude vehicles were determined using the same assumptions outlined above (so that the ratio of high-altitude to low-altitude idle emission rates equals the ratio of high-altitude to low-altitude exhaust rates for the same model years) with the following exception. The 1975-1976 LDT idle emission rates for the 0-6000 pound group were determined from the mean emissions of 1975 model year trucks tested in the Denver FY '74 EFP by the same method described for low-altitude 1975-1978 LDT's.

VIII. California Light-duty Automobiles

The idle emission rates of pre-1966 model year California vehicles equal the idle emission rates of pre-1968 model year low-altitude vehicles since both groups of vehicles are uncontrolled.

The idle deterioration rates, in percent of initial idle emissions, for the 1966+ California vehicles equal the percent FTP deterioration rates for the same model year California vehicles.

The 1966 through 1976 model year California LDV initial idle HC and NOx emission rates (and the 1966-80 CO rates) were derived from the mean idle emissions of samples of Los Angeles vehicles tested in the FY '71, FY '73, and FY '74 EFP. The same method of determining the initial emission rates was used for the California vehicles as was described above for low-altitude LDV's.

The 1977 and later California initial idle HC and NOx rates (and 1981+ CO rates) were determined by assuming that the ratios of initial idle rates of each California model year group LDV's/1975-1976 LDV's are equal to the ratios of initial FTP emission rates of the same categories of California LDV's.

IX. Other California Vehicle Categories

The idle emission rates for all other categories of California vehicles were determined using the assumptions outlined above for non-[illegible]fornia vehicles.

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